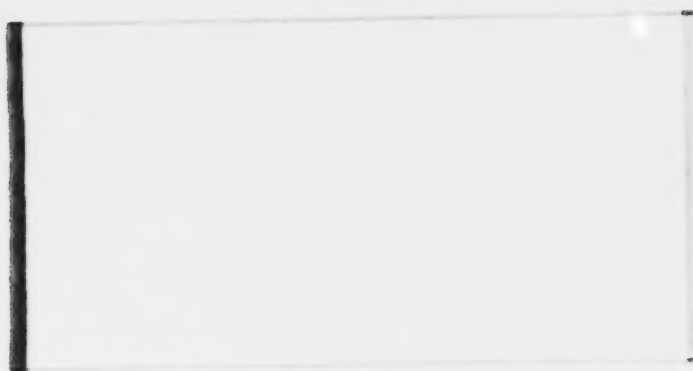




Ontario Hydro



RESEARCH DIVISION

COMPLIMENTARY COPY
Please Credit Ontario Hydro Research H
Reproduced in Whole or in Part.



**ontario hydro
research division**

VACUUM DRYING OF A SIMULATED
IRRADIATED FUEL TRANSPORTATION
ROAD CASK

Report No 85-324-K

D. Taralis
Engineer
Applied Structural & Solid
Mechanics Section
Mechanical Research Department

ABSTRACT

A full scale experimental study has been carried out to assess the feasibility and time required for vacuum drying the irradiated fuel road cask. Various tests have been conducted using a simulated cask and a trochoid vacuum pump under dry and wet conditions with and without the two fuel modules in the cavity. During the vacuum process, cavity pressure and temperatures as well as the quantity of water removed were monitored and recorded. Analysis of the measurements reveal that it would take up to 10 hours to completely dry the road cask. However, a shorter drying time would be expected when the decay heat of the irradiated fuel is considered. Further drying tests should be conducted to investigate the adequacy of a smaller vacuum pump.

job	file	date	report no.
740621-133-461	825.6	January 6, 1986	85-324-K



ontario hydro research division

EXECUTIVE SUMMARY

VACUUM DRYING OF A SIMULATED IRRADIATED FUEL TRANSPORTATION ROAD CASK

D. Taralis

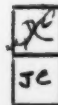
Engineer

Applied Structural & Solid Mechanics Section
Mechanical Research Department

This report describes the vacuum drying tests conducted for determining the time required to vacuum dry a two-module irradiated fuel road cask after it has been loaded in a water filled pool and subsequently drained. Full scale tests have been carried out under dry and wet conditions using a simulated cask and a Trochoid vacuum pump. The main results of this study include:

1. Cavity wall and bottom temperatures
2. Quantity of water evaporated.
3. Cavity pressure

Analysis of the test results indicate that 10 hours would be sufficient to completely dry the cask. Since the Trochoid pump does not appear to be very mobile, further tests using a smaller vacuum pump are recommended.



job	file	date	report no.
740621-133-461	825.6	January 6, 1986	85-324-K

TABLE OF CONTENTS

	<u>Page</u>
1.0 INTRODUCTION	1
2.0 VACUUM DRYING SYSTEM	1
2.1 Simulated Cask	2
2.2 Fuel Modules and Simulated Bundles	2
2.3 Vacuum Pump	2
3.0 INSTRUMENTATION	2
4.0 TEST PROCEDURE	3
5.0 TEST PROGRAM	3
6.0 TEST RESULTS	3
7.0 CONCLUSIONS AND RECOMMENDATIONS	5
ACKNOWLEDGEMENTS	5
REFERENCES	7
DISTRIBUTION	last page

LIST OF FIGURES

1. Experimental Set up for Vacuum Drying Tests
2. Simulated Cask (Cavity Dimensions = 1.026 m x 1.48 m 1.35 m)
3. Two Fuel Modules Placed in Cavity of Simulated Cask
4. Trochoid Vacuum Pump (TR-400)
5. Instrumentation and Vacuum Pump Connections to the Simulated Cask
6. AUTO DATA 10 Acquisition System
7. Cavity Pressure Under Dry Conditions
8. Cavity Wall and Bottom Temperatures Under Dry Conditions
9. Cavity Pressure With Water Depth = 100 mm
10. Quantity of Water Removed as Vapour with Water Depth = 100 mm
11. Cavity Wall and Bottom Temperatures with Water Depth = 100 mm
12. Cavity Pressure with Water Depth = 100 mm and 1 kW Heat Input
13. Cavity Wall and Bottom Temperatures with Water Depth = 100 mm and 1 kW Heat Input
14. Cavity Pressure with 5 litres of Water
15. Cavity Wall and Bottom Temperatures with 5 litres of Water
16. Cavity Pressure with 10 litres of Water
17. Cavity Wall and Bottom Temperatures with 10 litres of water
18. Cavity Pressure with 15 litres of Water
19. Cavity Wall and Bottom Temperatures with 15 litres of Water
20. Cavity Pressure with 20 litres of Water (Warm Conditions)
21. Cavity Wall and Bottom Temperatures with 20 litres of Water (Warm Conditions)
22. Cavity Pressure with 20 litres of Water (Cool Conditions)
23. Cavity Wall and Bottom Temperatures with 20 litres of water (Cool Conditions)
24. Cavity Pressure for Water Filled and Drained Cavity with Two Fuel Modules
25. Cavity Wall and Bottom Temperatures for a Water Filled and Drained Cavity
26. Cavity Pressure with Two Pump-Stops for 5 litres of Water
27. Cavity Pressure Rise with Two Pump-Stops for 5 litres of Water

LIST OF TABLES

1. List of Vacuum Tests Conducted



**ontario hydro
research division**

To Mr. H.N. Isaac
Manager
Nuclear Materials Management
Design & Development - Gen

VACUUM DRYING OF A SIMULATED IRRADIATED
FUEL TRANSPORTATION ROAD CASK

D. Taralis

1.0 INTRODUCTION

At existing generating stations, the loading operation of an irradiated fuel road cask will be carried out in a water filled pool. To assess the feasibility and the time required for vacuum drying the two-module cask, a full scale experimental study has been carried out.

This report describes in detail the vacuum drying system used for conducting the tests, the instrumentation employed to measure the required parameters including the test procedure and test program, presents and discusses the results and states the major findings of the study.

2.0 VACUUM DRYING SYSTEM

Figure 1 shows a photograph of the experimental apparatus used in carrying out the vacuum drying tests. It consists of the following three main components:

- i) A simulated cask
- ii) Two fuel modules and simulated bundles
- iii) A vacuum pump

These components are briefly described below.

job	file	date	report no.
740621-133-461	825.6	January 6, 1986	85-324-K

2.1 Simulated Cask

The experimental cask shown in Figure 2 has been built to simulate the cavity of an irradiated fuel two-module cask. This cask has been previously used to carry out heat transfer tests for determining the maximum fuel temperature. The entire cask is made of carbon steel and is designed according to the ASME pressure vessel code for 700 (KPa)_g as well as for full vacuum. To reduce the size of the evacuation port to that in the real cask, an orifice of 30 mm in diameter was installed at the outlet of the simulated cask.

2.2 Fuel Modules and Simulated Bundles

The cavity of the road cask can accommodate up to two fuel modules (see Figure 3). Each module consists of 48 tubes and each tube can carry two fuel bundles. Thus, a maximum of 192 fuel bundles can be transported in one shipment. To avoid unnecessary cost, the fuel bundles have been modelled approximately. The small deviation from the actual bundles is considered to be negligible.

2.3 Vacuum Pump

The evacuation of the cavity was accomplished using a single-stage Trochoid pump (TR-400). This is shown in Figure 4. It is an oil-sealed pump and operates on the same principle as the circulating piston engine. Its piston has the shape of an ellipse while the shape of the housing is that of a cardioid. All Trochoid pumps are designed for vacuum processes with operating requirements above 0.1 Torr. The pump features an adjustable gas ballast valve for minimizing condensation of vapours inside the pump. Detailed description of the Trochoid pump can be found in reference/1/.

3.0 INSTRUMENTATION

The following instrumentation has been used in the vacuum drying tests:

- i) An electronic pressure transducer suitable for measuring pressures from 0.1 Torr to 1000 Torr. For visual pressure reading a dial type pressure gauge was also used.
- ii) Four Type T thermocouples suitable for measuring the cavity wall and bottom temperatures including the fuel module temperatures.
- iii) A displacement transducer for measuring the water level in the cask and hence the quantity of water evaporated.

The pressure transducer, pressure gauge, thermocouple and displacement transducer connections were made through the left lid opening (see Figure 5). The output signals from the instrumentation were monitored and recorded continuously using the AUTO DATA 10 acquisition system as shown in Figure 6.

4.0 TEST PROCEDURE

The basic task is to dry the cavity of a simulated cask under various conditions using the Trochoid vacuum pump (TR-400). With the pump operating, the cavity pressure will decrease to the saturation pressure of water corresponding to the cavity wall temperature. During the drying process, the cavity pressure tends to remain constant until all of the water has evaporated. When the cavity is essentially dry, the pressure will continue to decrease until the operating limit of the pump is reached.

5.0 TEST PROGRAM

To determine the time required to dry a two-module cask after it has been loaded with irradiated fuel in a water filled pool and subsequently drained, a series of vacuum drying tests have been carried out. Table 1 gives a list of the tests conducted and the parameters monitored during the tests.

As this table indicates, the first test involved a dry cavity. In the second and third tests, the cavity contained a large quantity of water, first without heating and then with 1 kW heating. The change in the water surface height due to evaporation was measured and converted to litres of water using a float attached to a displacement transducer. Tests 4 to 7 dealt with known quantities of water in the cavity. The last case represented a completely filled and drained cavity with two fuel modules containing 192 simulated fuel bundles.

6.0 TEST RESULTS

The results obtained for the tests listed in Table 1 are presented and discussed below.

The pressure-time curve for an empty cavity under dry conditions (Test #1) is shown in Figure 7. The cavity pressure, as can be seen from this figure, decreases very rapidly down to 2 Torr within 6 minutes. The minimum pressure that can be attained by the vacuum pump including the effects of minute leaks in the system is approximately 0.25 Torr. During the vacuum process, the wall and bottom temperatures of the vessel remain constant (see Figure 8) as expected since there is no heat transfer into or out of the system.

The measurements made for Test #2 are shown in Figures 9 to 11. Figure 9 shows the pressure-time curve and Figure 10 shows the quantity of water removed from the cavity as a vapour. As this figure indicates, the rate of evaporation is highest and constant during the first 2.5 hours. As the cavity wall and bottom temperatures decrease, the evaporation rate also decreases. These temperatures are shown in Figure 11. During the vacuum process, the bottom temperature decreases significantly while the wall temperature remains essentially constant.

The results of Test #3 include the effects of 1 kW heat input to the water in the cavity. All other conditions are identical to those of Test #2. Figure 12 shows the pressure history and Figure 13 shows the cavity wall and bottom temperatures. The heat added to the system has the effect of maintaining the cavity pressure at a higher level while water is evaporating at a higher rate. Also, the cavity bottom temperature is much higher compared to Figure 11 and it appears to approach a constant value.

Pressure-time curves and cavity wall and bottom temperatures for Tests #4 to 7 are shown in Figures 14 through 21. All these figures exhibit the same characteristics. The steep changes in the pressure-time curves indicate that practically all the water in the cavity has evaporated. The time required to evaporate a given quantity of water is not only a function of the quantity of water in the cavity but also a function of the initial temperature of the cavity surfaces including the temperature of the water. This is illustrated by repeating Test #7. The pressure and cavity temperatures for this case are shown in Figures 22 and 23. A comparison of Figure 20 with Figure 22 shows an increase in drying time by approximately 3 hours when the initial cavity wall temperature is 5°C lower. This is due to the fact that evaporation rates decrease significantly as the water temperature approaches the freezing point.

The last Test (#8) is of course of most interest since it simulates very closely the actual conditions of a two-module cask. The results of this test are shown in Figures 24 and 25. Referring to Figure 24, one can determine when the cavity walls and fuel modules are approximately dry. This is not as obvious as in the previous tests. Because of the many surfaces involved, the change in the cavity pressure is not as abrupt. However, with the aid of Figure 25, one can assume with a high degree of confidence that within 10 hours the two-module cask would be completely dry. This time is conservative since the decay heat from the irradiated fuel will greatly enhance evaporation rates and thereby reduce the time to dryness. It should be mentioned that there is no apparent reason why the top module temperature is lower than that of the bottom module.

To check that the steep change in the pressure time curve is in fact an indication of reaching dry conditions, Test #3 was repeated with the pump stopped twice for approximately 45 minutes each time. The first stop was made when the cavity pressure reached 4.91 Torr. The second stop was made when the cavity pressure was 0.25 Torr. The entire pressure-time curve for this case is shown in Figure 26 and the pressure rises during the two pump stops are illustrated in Figure 27. As this figure indicates, the pressure rise is much higher during the first stop particularly during the first 5 minutes. The pressure rise for the second stop is much lower and is a linear function of time.

Figure 27 also shows the pressure rise during the pump-stop of Test #1 (see Figure 7). This pressure rise is solely due to the air leakage into the cavity. Due to the fact that this curve compares relatively well with that of the second pump-stop, it is reasonable to assume that the steep changes in the pressure time curves indicate that essentially all the residual water in the cavity has evaporated.

7.0 CONCLUSIONS AND RECOMMENDATIONS

- i) The evacuation of the simulated cask down to approximately 0.25 Torr under dry conditions is accomplished within 1 hour. During this process, there is no heat transfer into or out of the system.
- ii) Evaporation rates under wet conditions start out high at the beginning of the drying process and as heat is taken out of the system, the evaporation rates and cavity temperatures decrease until the vessel is completely dry.
- iii) The time required to remove a given quantity of water from the cavity depends on both the quantity of water to be removed and the initial thermal conditions of the system.
- iv) For all practical purposes, the cavity can be considered to be dry immediately after the abrupt changes in the pressure time curves have taken place.
- v) For a water-filled and drained cavity containing two fuel modules, the time required to completely dry the cask would be approximately 10 hours.
- vi) Although the Trochoid pump (TR-400) appears to be suitable for the vacuum drying of a two-module cask, it is recommended that the adequacy of a smaller vacuum pump be investigated since a smaller size pump is preferred.

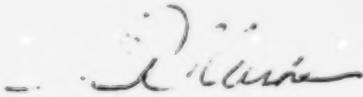
ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Mr. K.E. Nash from the Nuclear Materials Management Department for the useful discussions

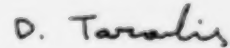
during the progress of this work. Mr. J. Hayhurst of the Transmission Station Department is also greatly acknowledged for providing the vacuum pump and for his patience and understanding.

Approved by:

Submitted by:



G.J. Clarke
Manager
Mechanical Research Dept
JK



D. Taralis
Engineer
Applied Structural &
Solid Mechanics Section

Reviewed by:



T.P. Byrne
Unit Head
Stress Analysis & Heat Transfer
Applied Structural &
Solid Mechanics Section

DT/lct

REFERENCES

1. Leybold-Heraeus, "Trochoid Piston Pumps TR-400 and TR-630", Operating Instructions, Bulletin 1-92.

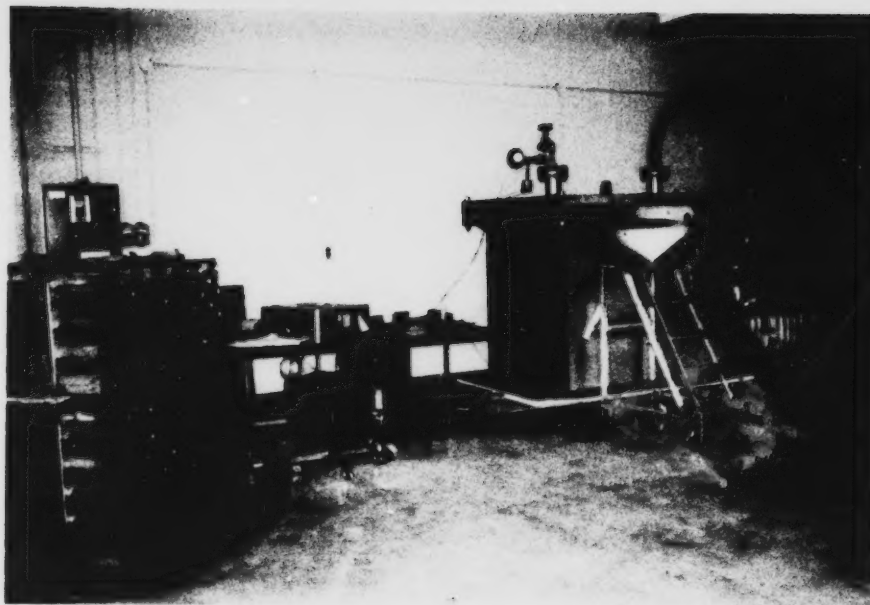


FIGURE 1
EXPERIMENTAL SET UP FOR VACUUM DRYING TESTS

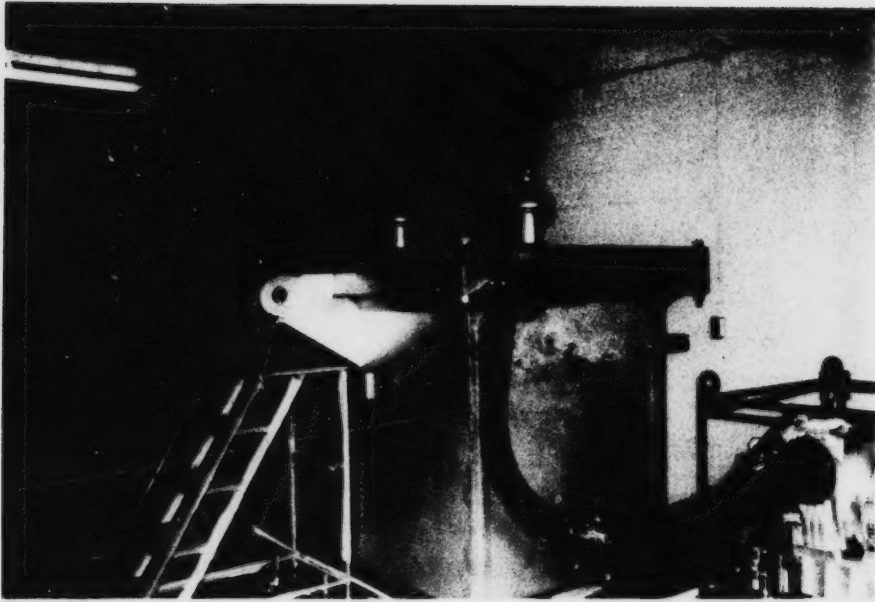


FIGURE 2
SIMULATED CASK
(CAVITY DIMENSIONS = 1.026m X 1.48m X 1.35m)

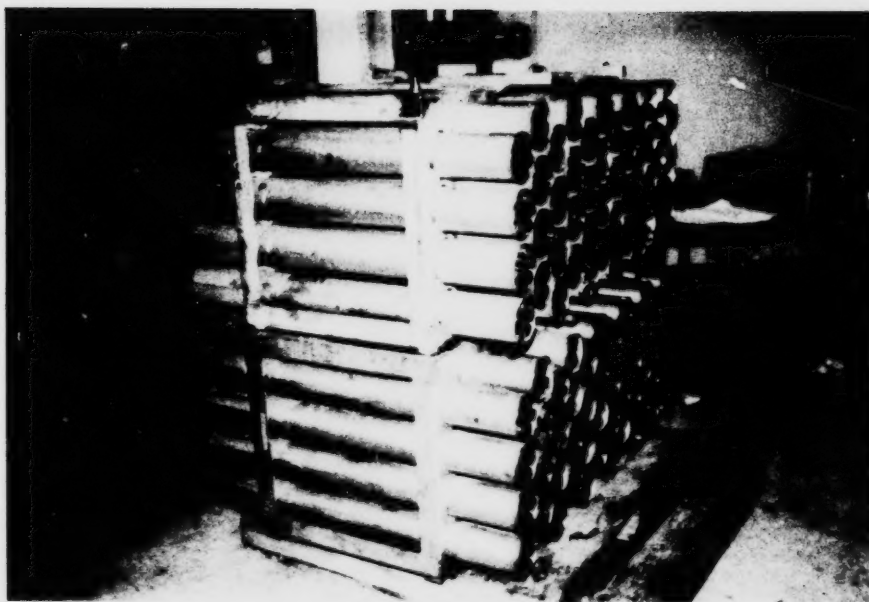


FIGURE 3
TWO FUEL MODULES PLACED IN CAVITY OF SIMULATED CASK

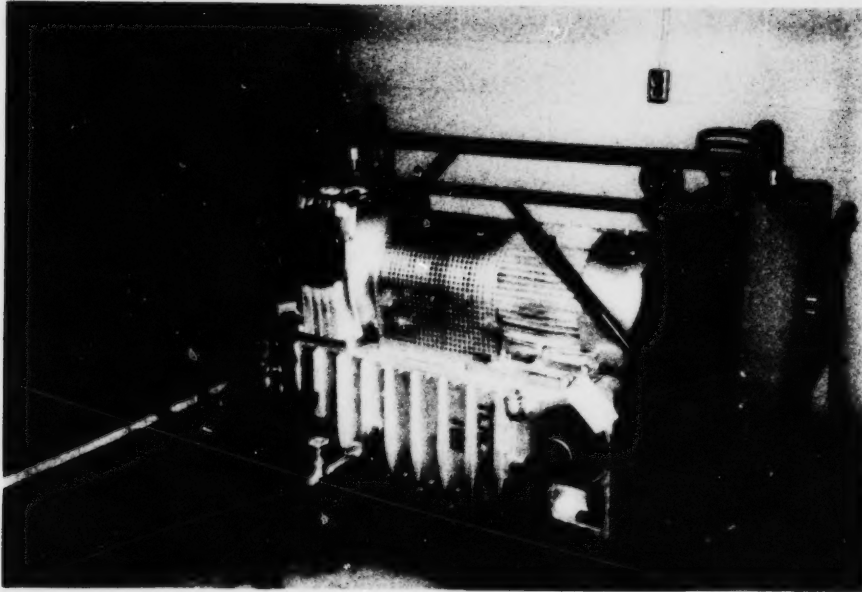


FIGURE 4
TROCHOID VACUUM PUMP (TR-400)

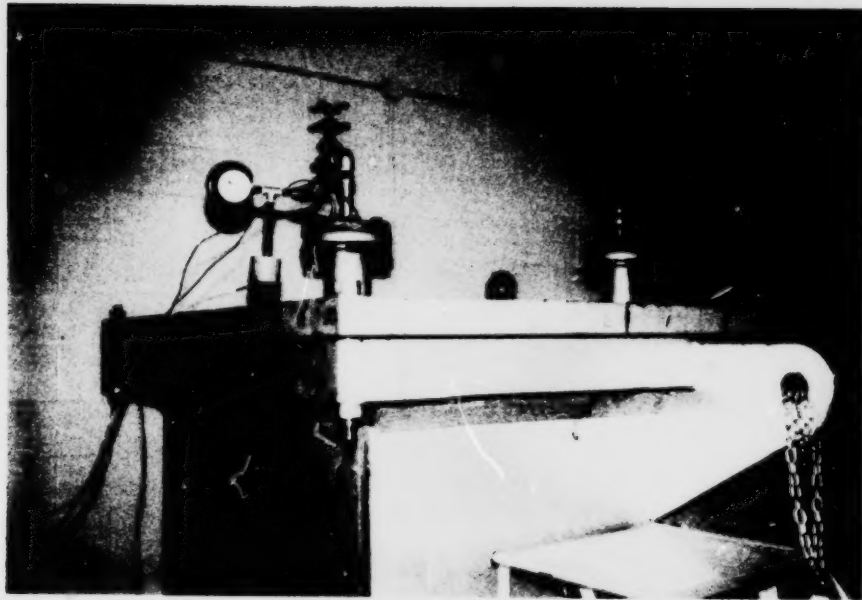


FIGURE 5
INSTRUMENTATION AND VACUUM PUMP CONNECTIONS
TO THE SIMULATED CASK

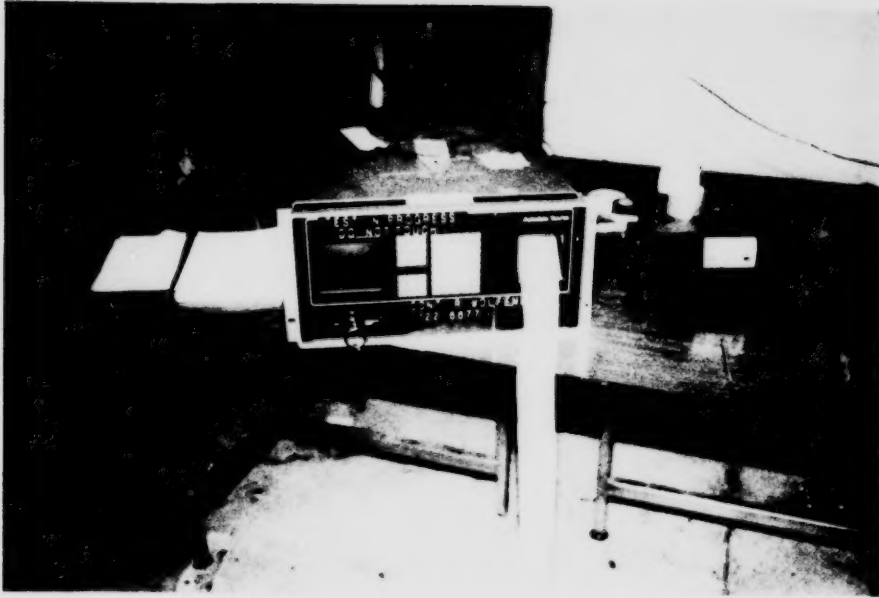


FIGURE 6
AUTO DATA 10 ACQUISITION SYSTEM

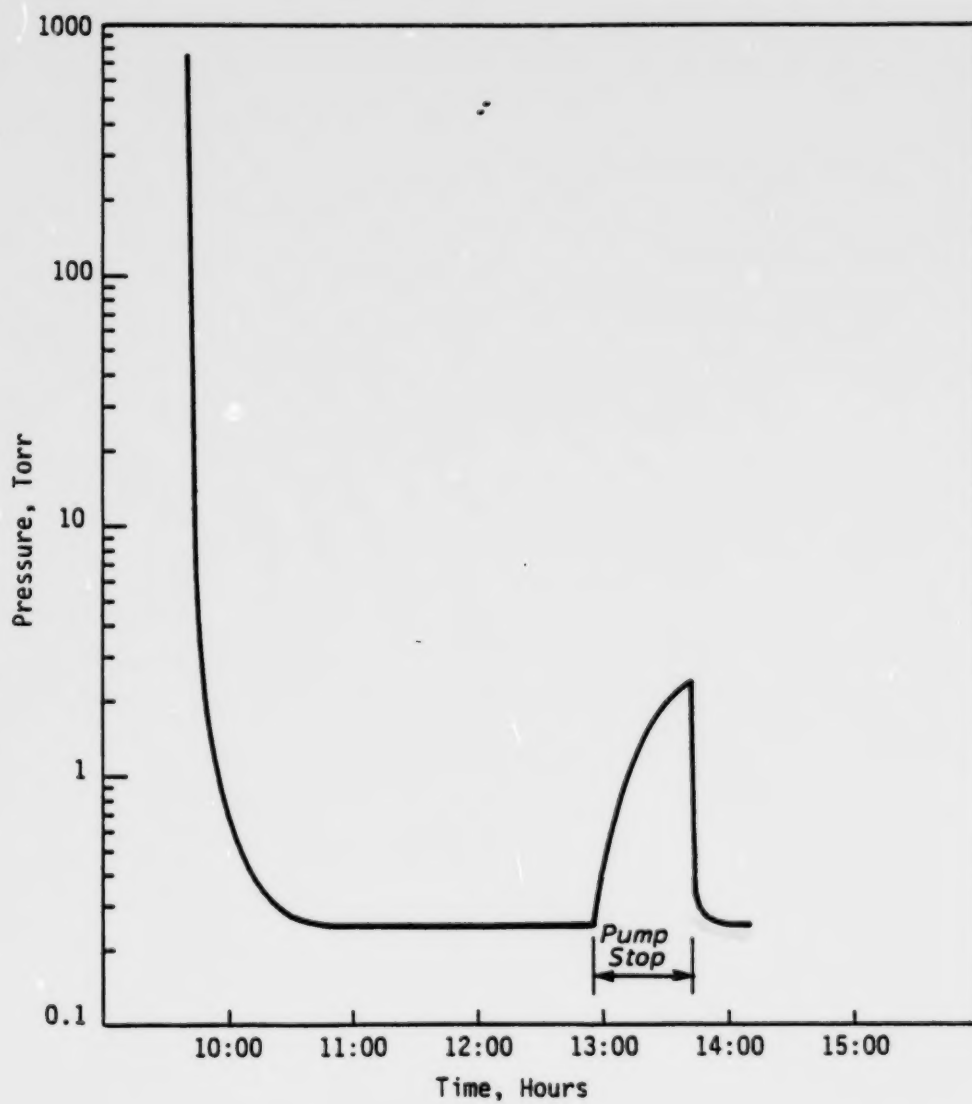


FIGURE 7
CAVITY PRESSURE UNDER DRY CONDITIONS

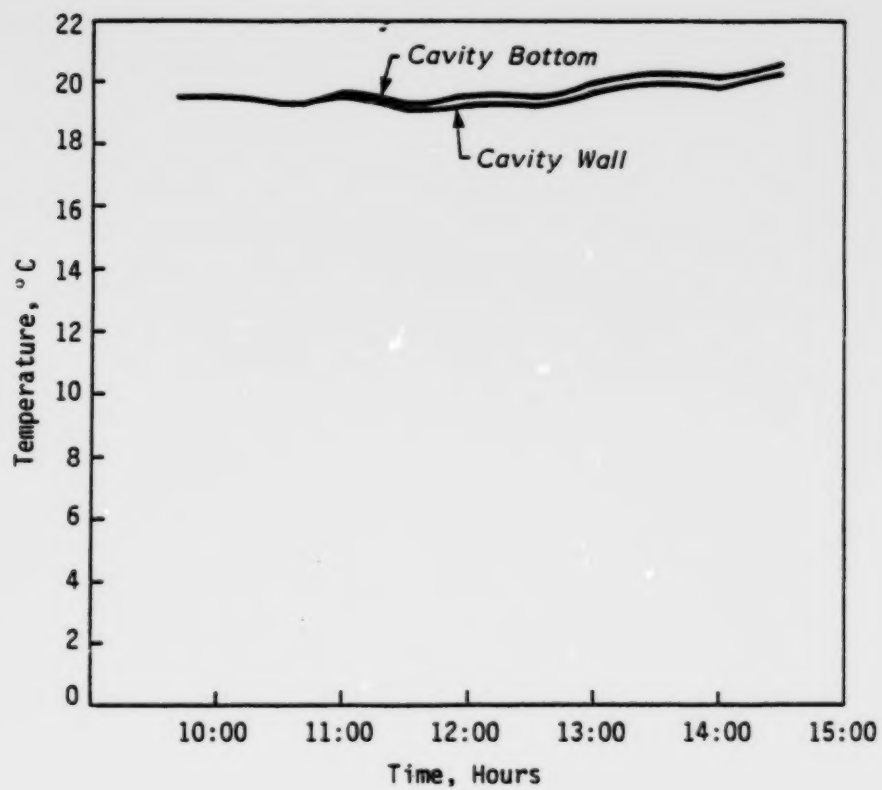


FIGURE 8
CAVITY WALL AND BOTTOM TEMPERATURES
UNDER DRY CONDITIONS

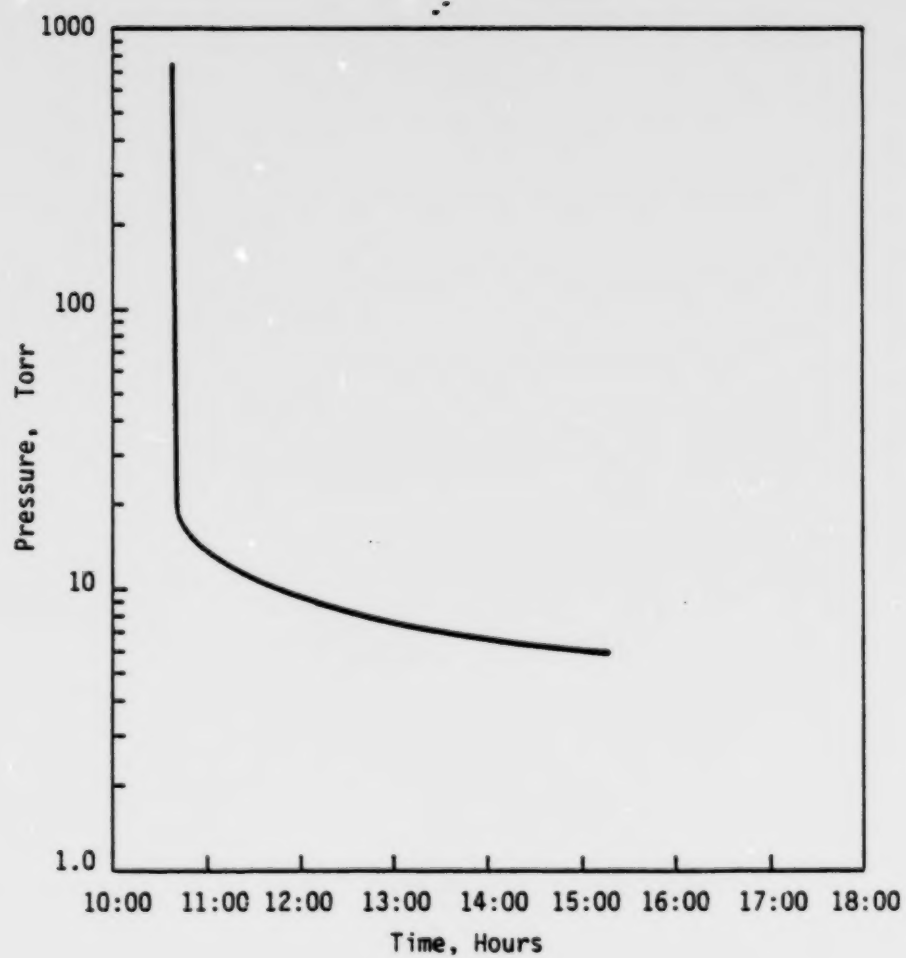


FIGURE 9
CAVITY PRESSURE WITH WATER DEPTH = 100mm

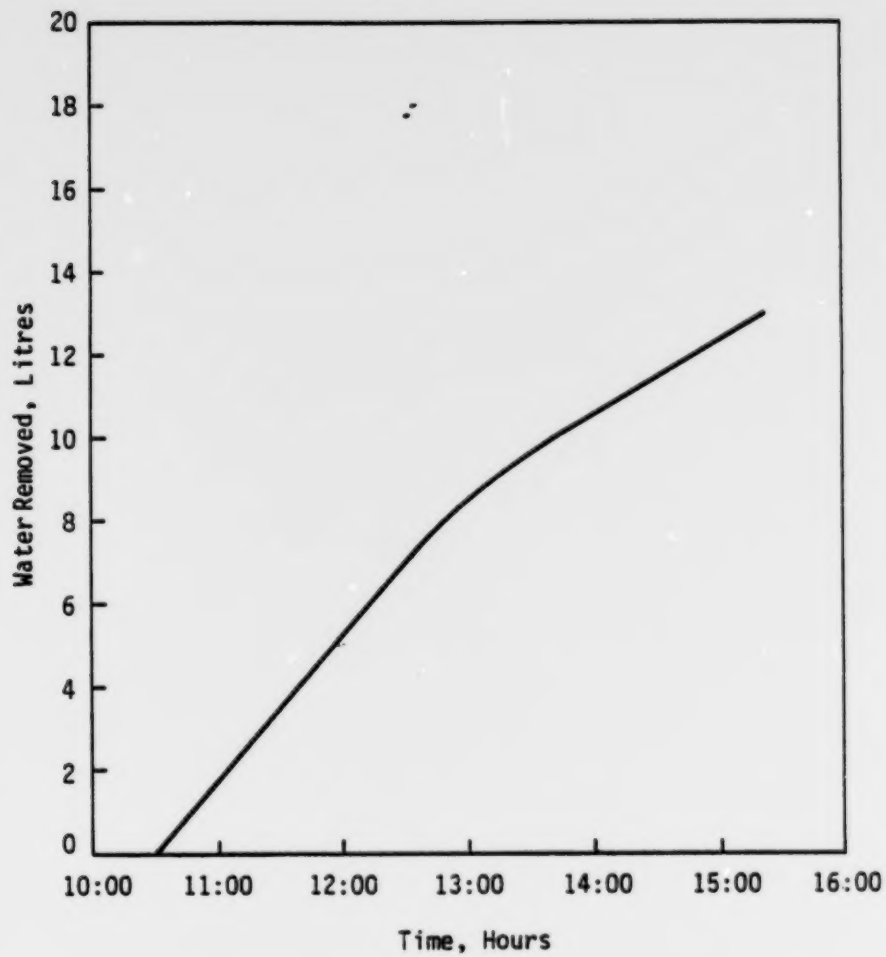


FIGURE 10
QUANTITY OF WATER REMOVED AS VAPOUR
WITH WATER DEPTH = 100 mm

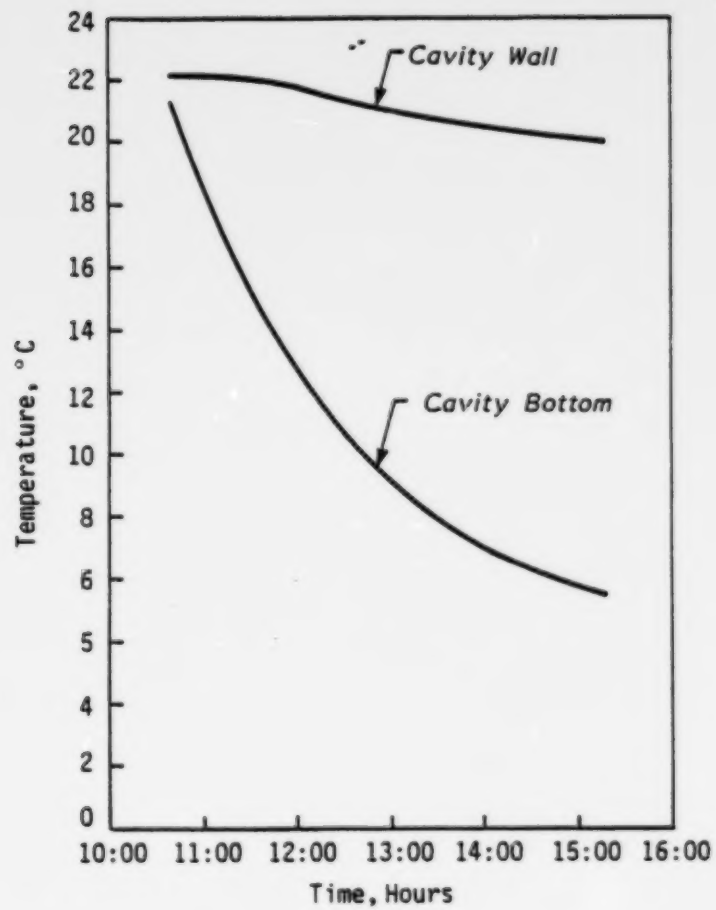


FIGURE 11
CAVITY WALL AND BOTTOM TEMPERATURES
WITH WATER DEPTH = 100 mm

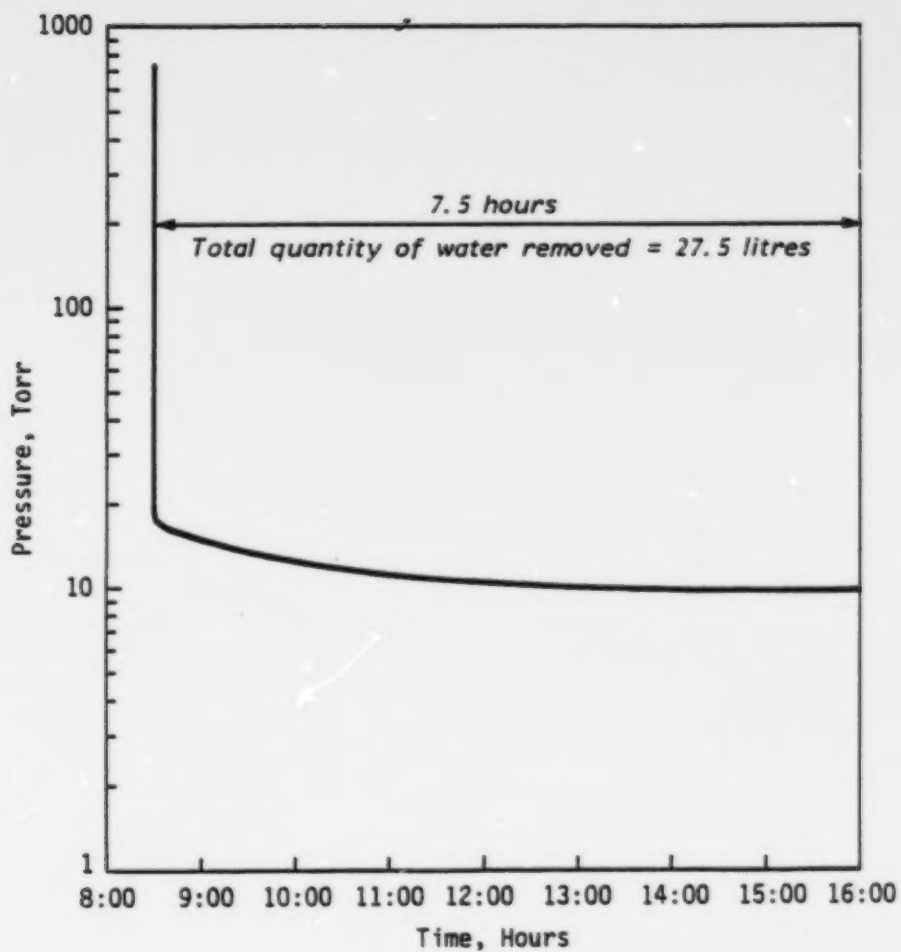


FIGURE 12
CAVITY PRESSURE WITH WATER DEPTH = 100 mm
AND 1 kW HEAT INPUT

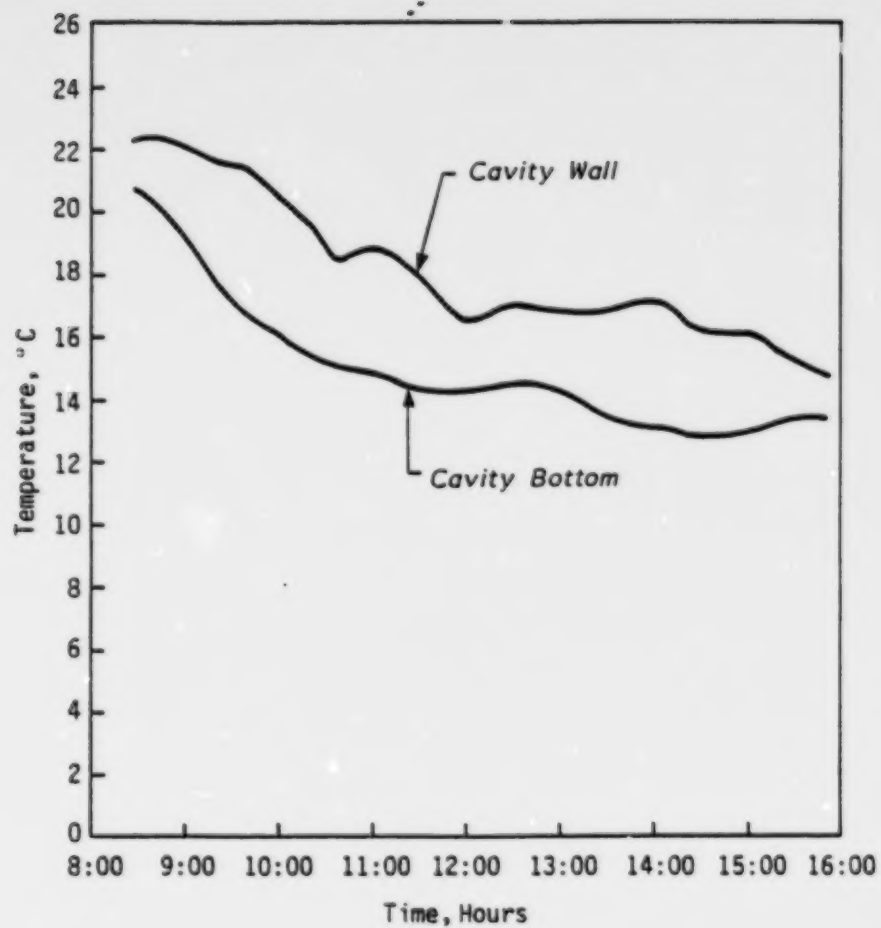


FIGURE 13
CAVITY WALL AND BOTTOM TEMPERATURES
WITH WATER DEPTH = 100mm AND 1 kW HEAT INPUT

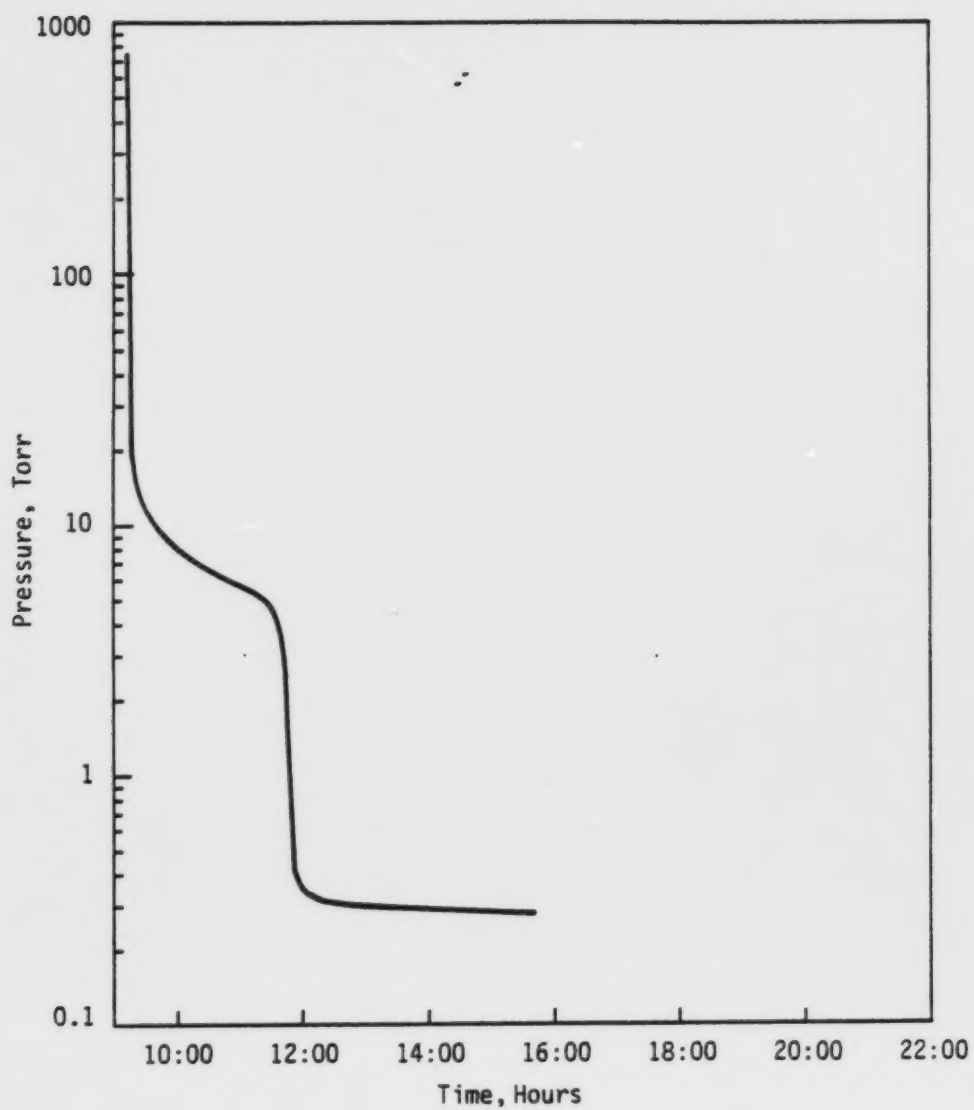


FIGURE 14
CAVITY PRESSURE WITH 5 LITRES OF WATER

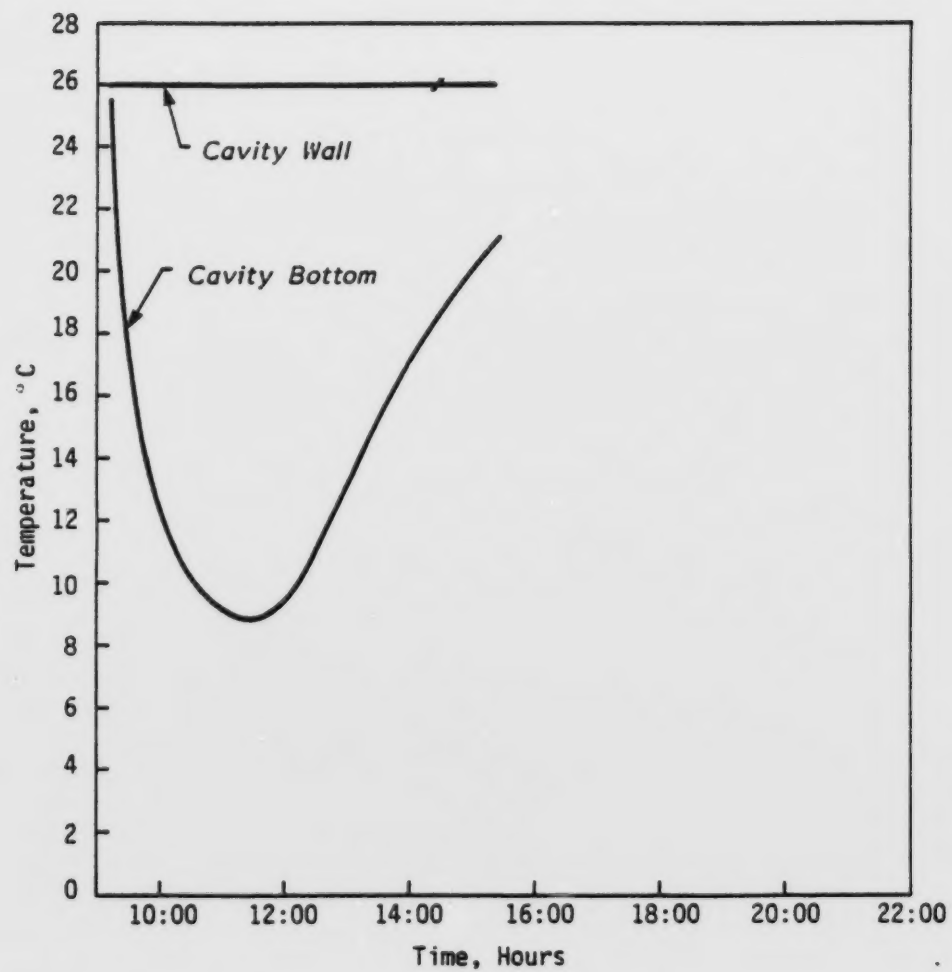


FIGURE 15
CAVITY WALL AND BOTTOM TEMPERATURES
WITH 5 LITRES OF WATER

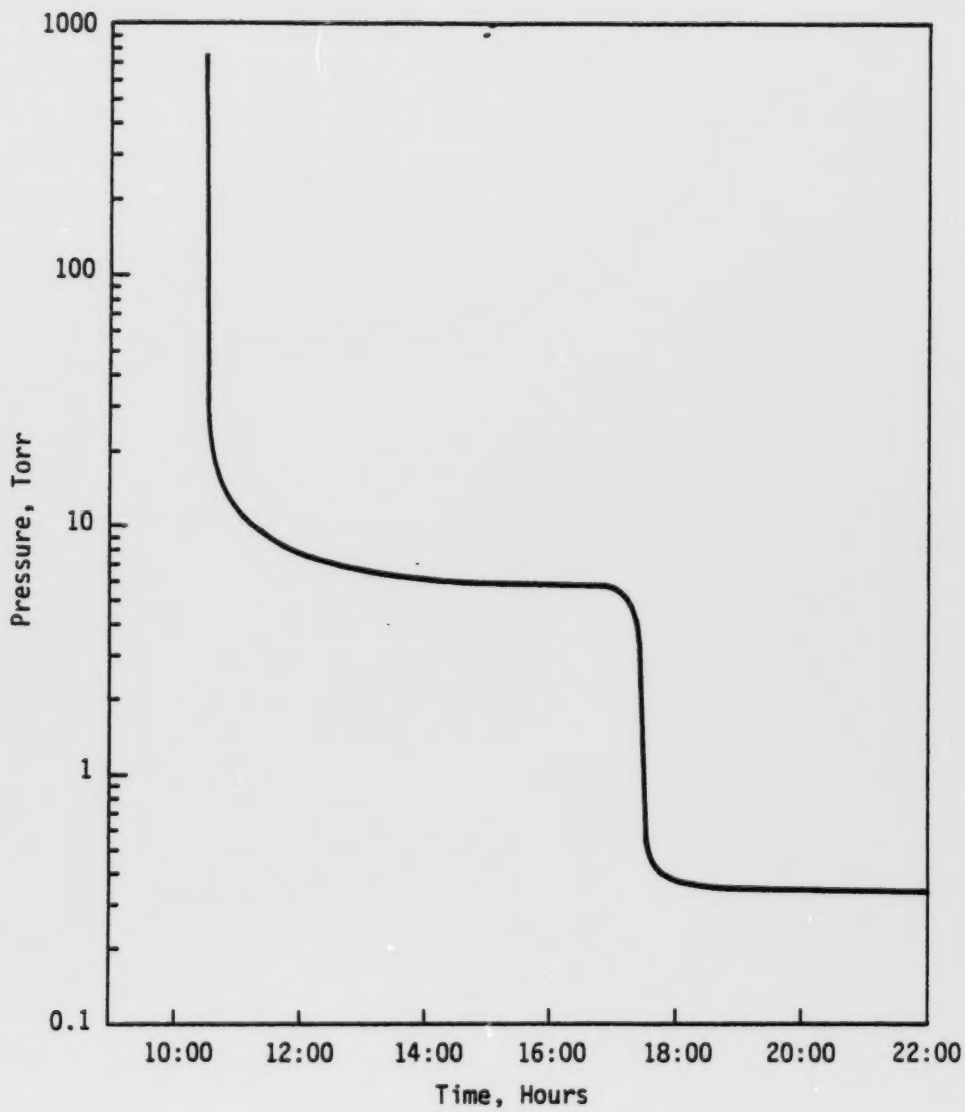


FIGURE 16
CAVITY PRESSURE WITH 10 LITRES OF WATER

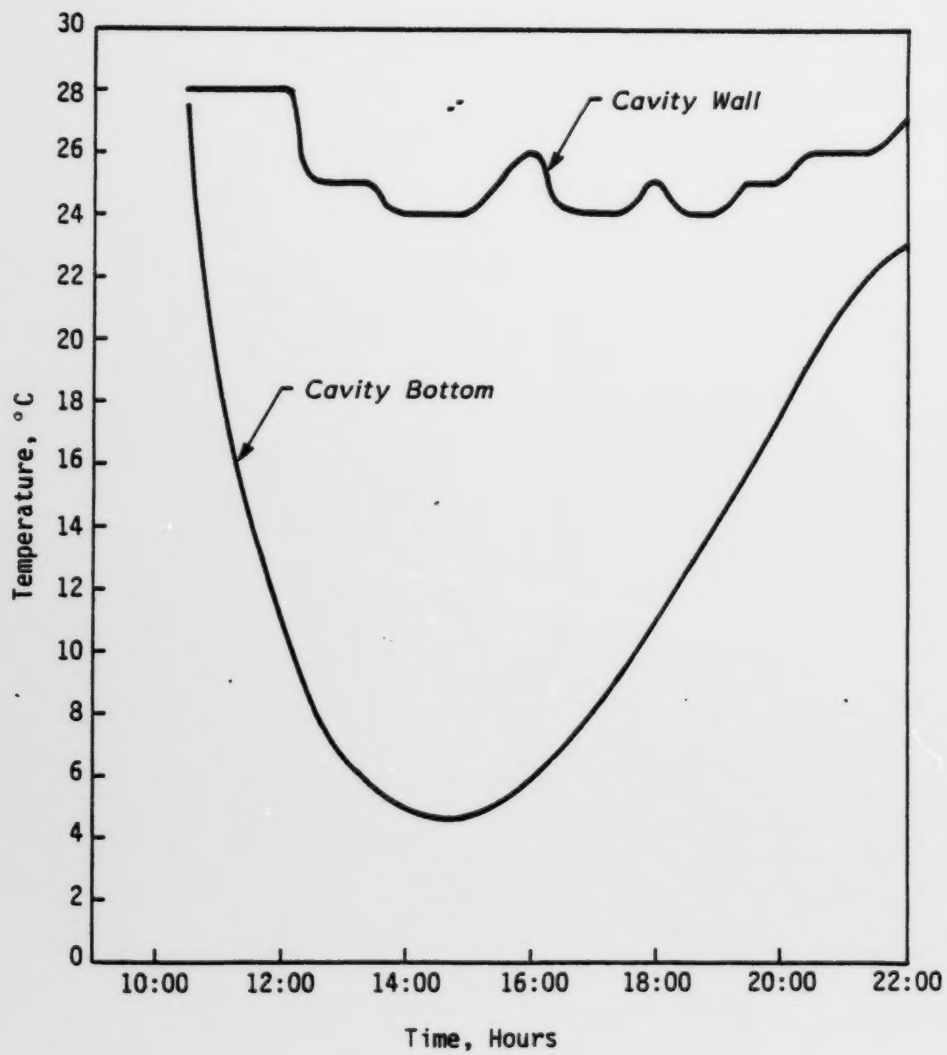


FIGURE 17
CAVITY WALL AND BOTTOM TEMPERATURES
WITH 10 LITRES OF WATER

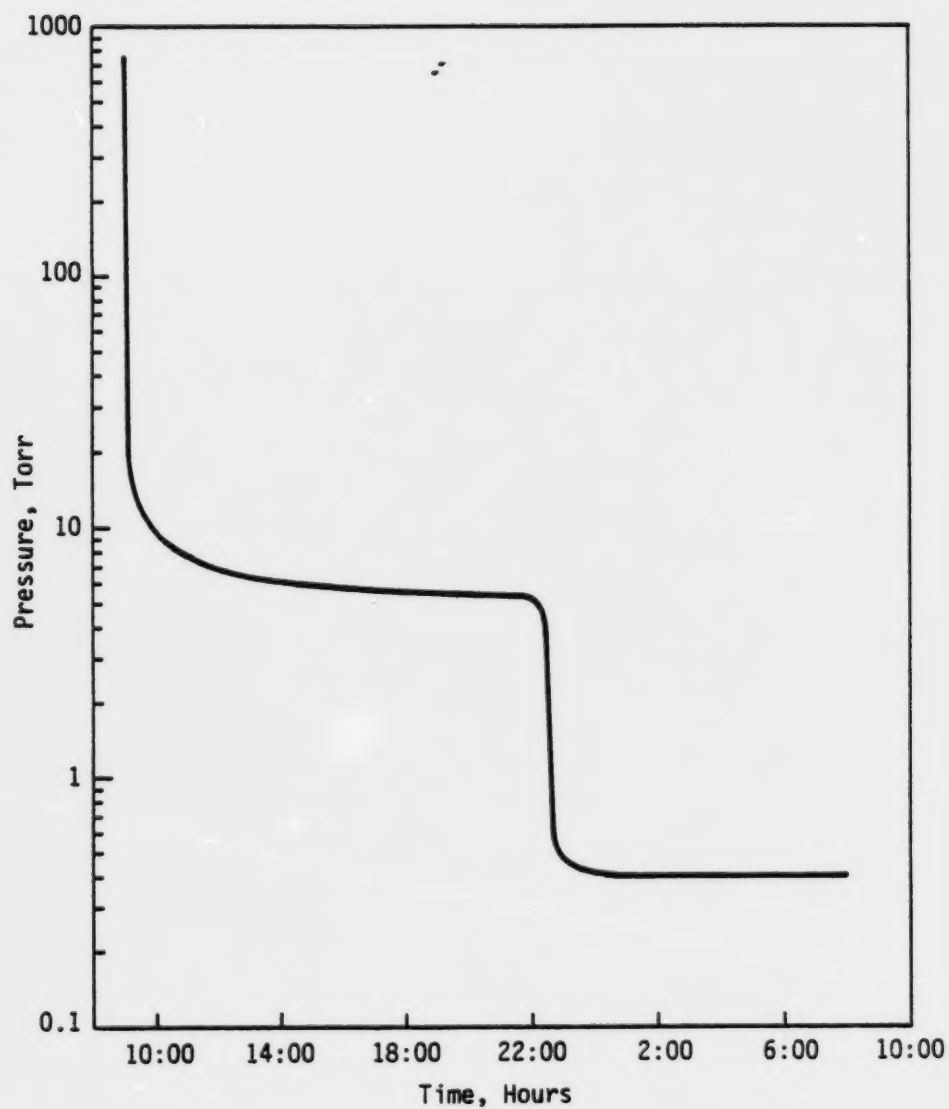


FIGURE 18
CAVITY PRESSURE WITH 15 LITRES OF WATER

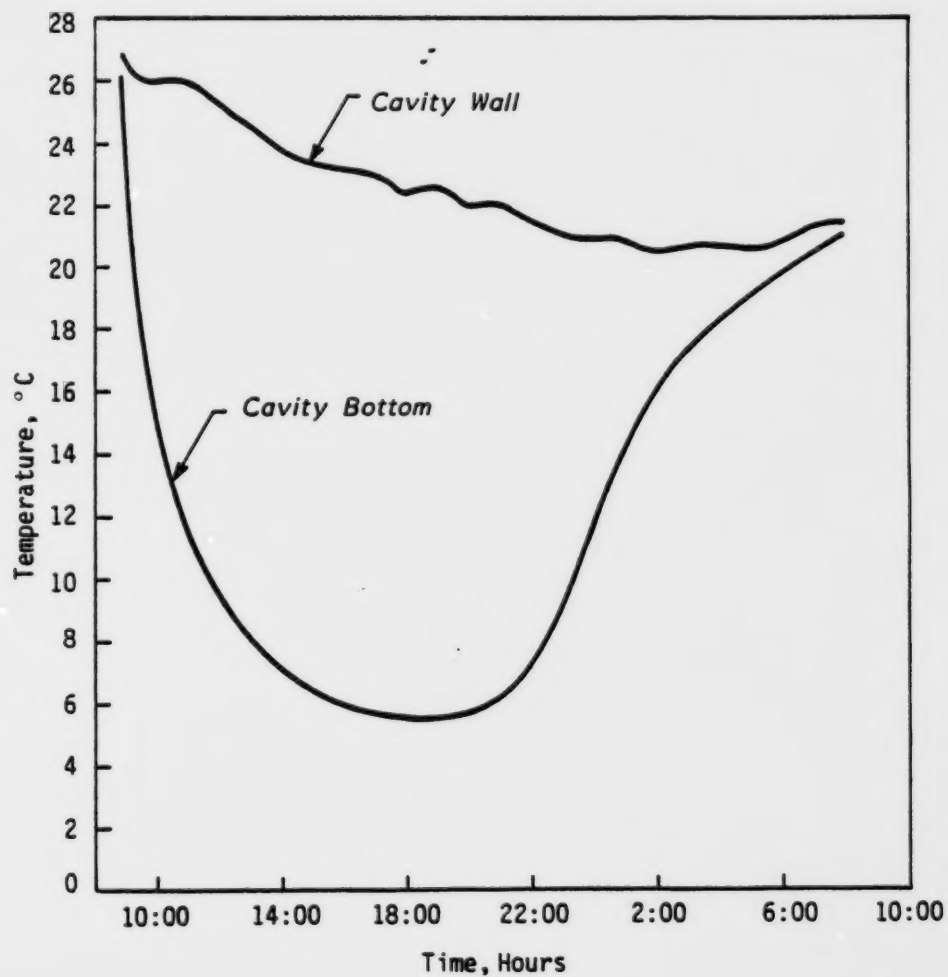


FIGURE 19
CAVITY WALL AND BOTTOM TEMPERATURES
WITH 15 LITRES OF WATER

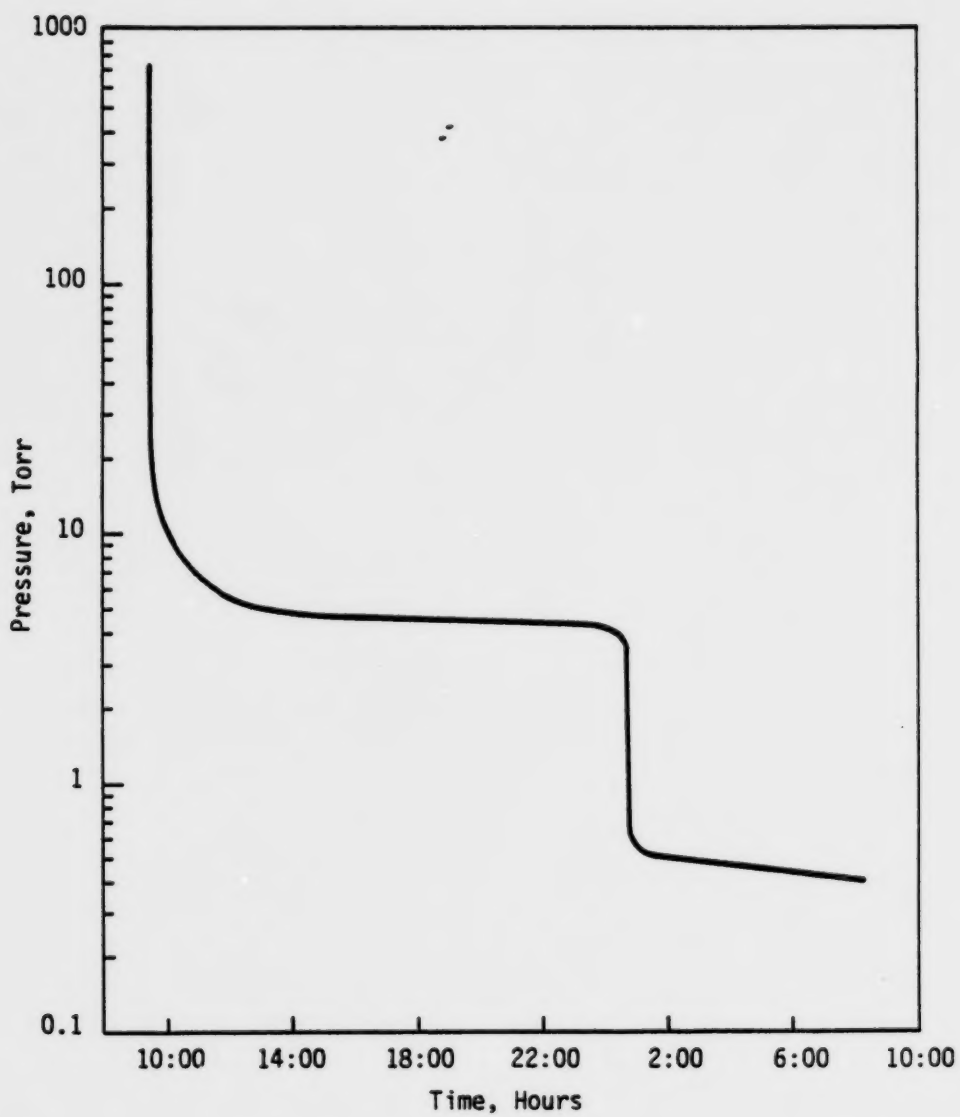


FIGURE 20
CAVITY PRESSURE WITH 20 LITRES OF WATER
(WARM CONDITIONS)

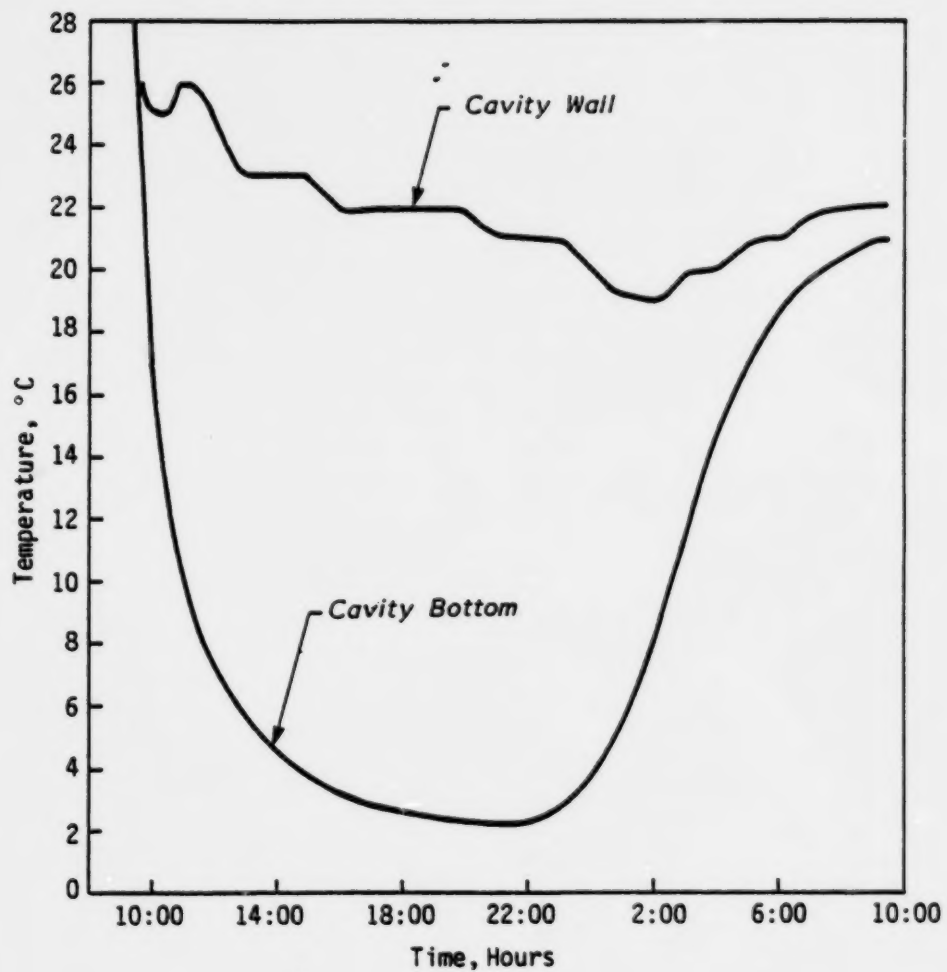


FIGURE 21
CAVITY WALL AND BOTTOM TEMPERATURES
WITH 20 LITRES OF WATER
(WARM CONDITIONS)

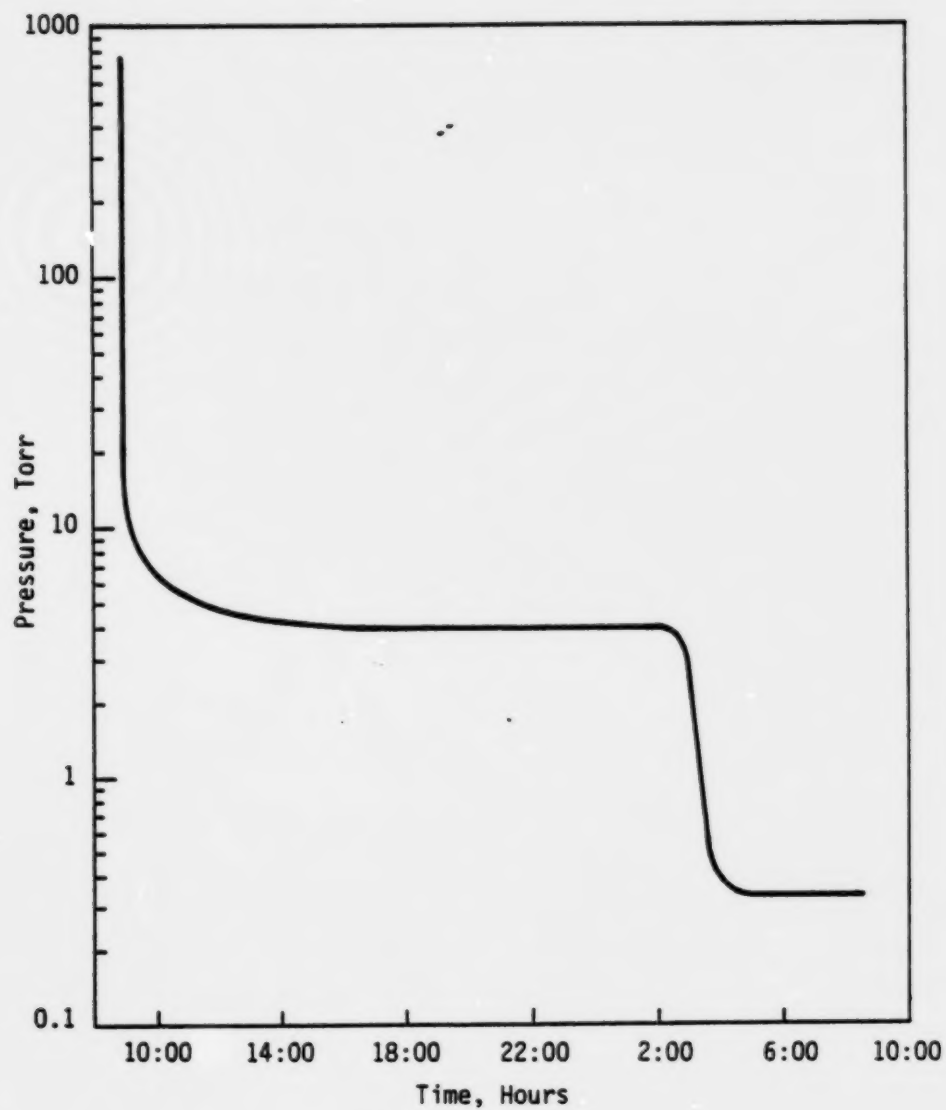


FIGURE 22
CAVITY PRESSURE WITH 20 LITRES OF WATER
(COOL CONDITIONS)

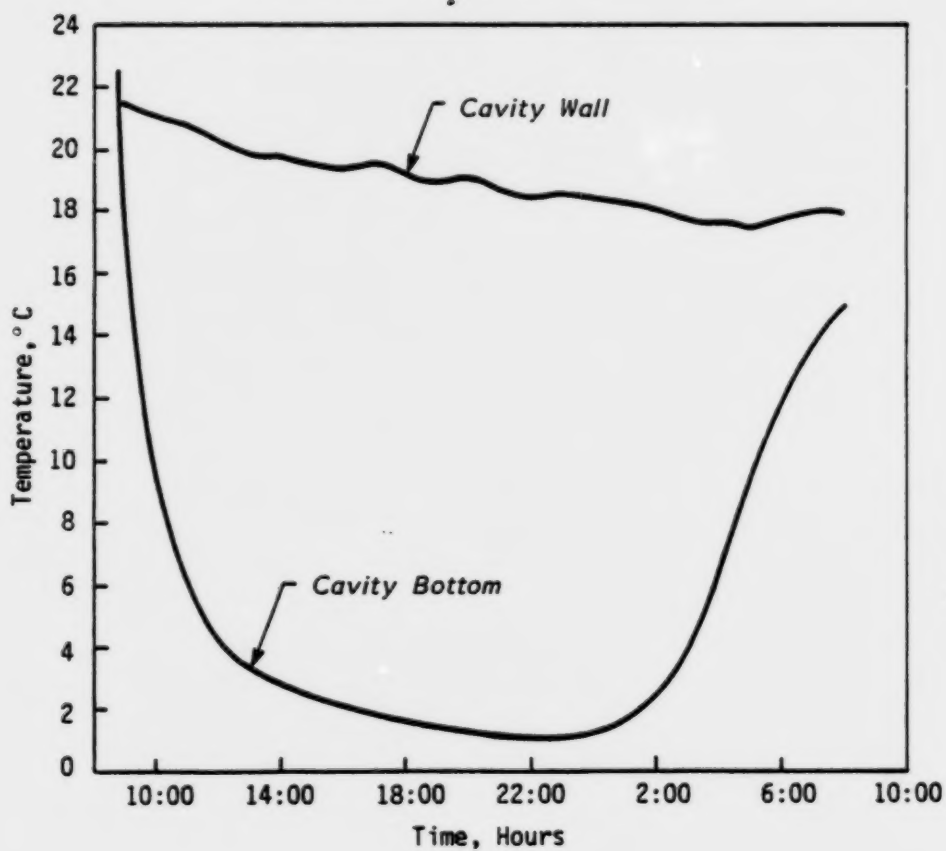


FIGURE 23
CAVITY WALL AND BOTTOM TEMPERATURES
WITH 20 LITRES OF WATER
(COOL CONDITIONS)

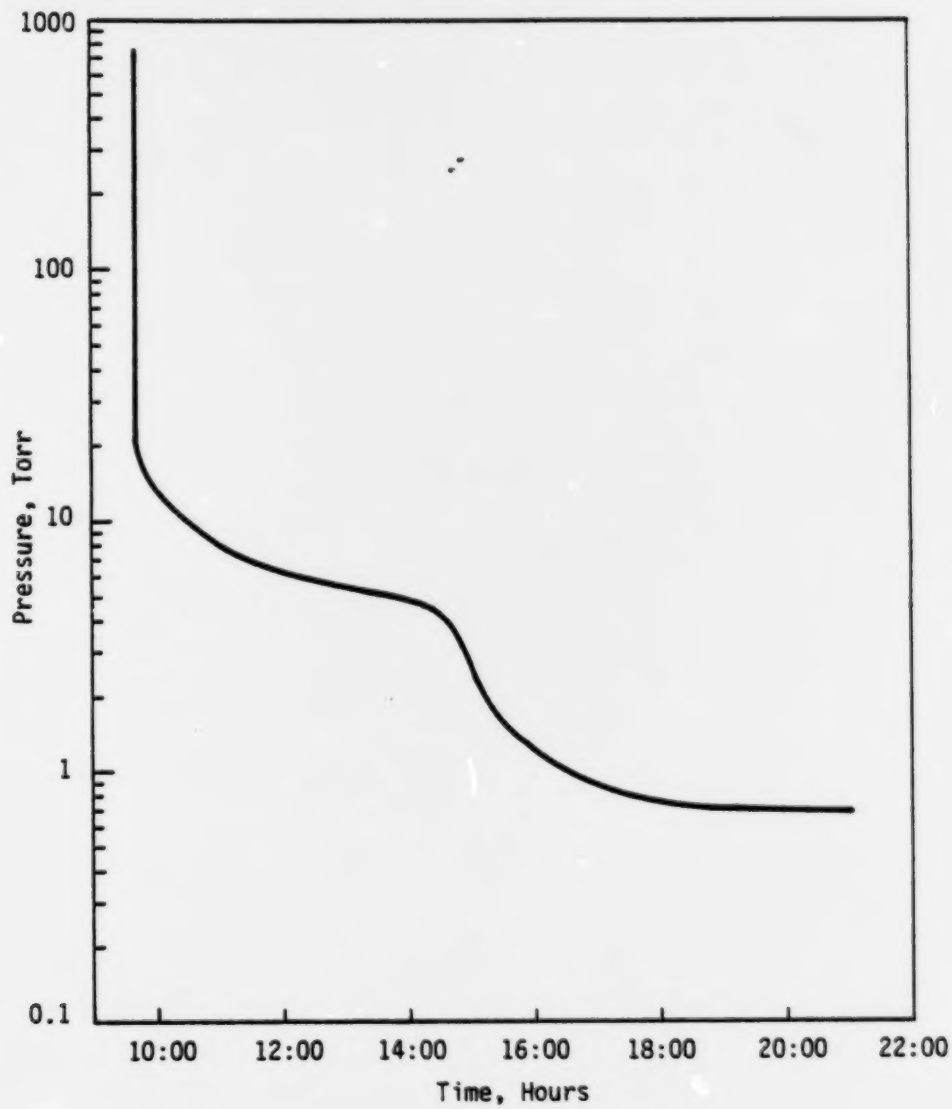


FIGURE 24
CAVITY PRESSURE FOR WATER FILLED AND
DRAINED CAVITY WITH TWO FUEL MODULES

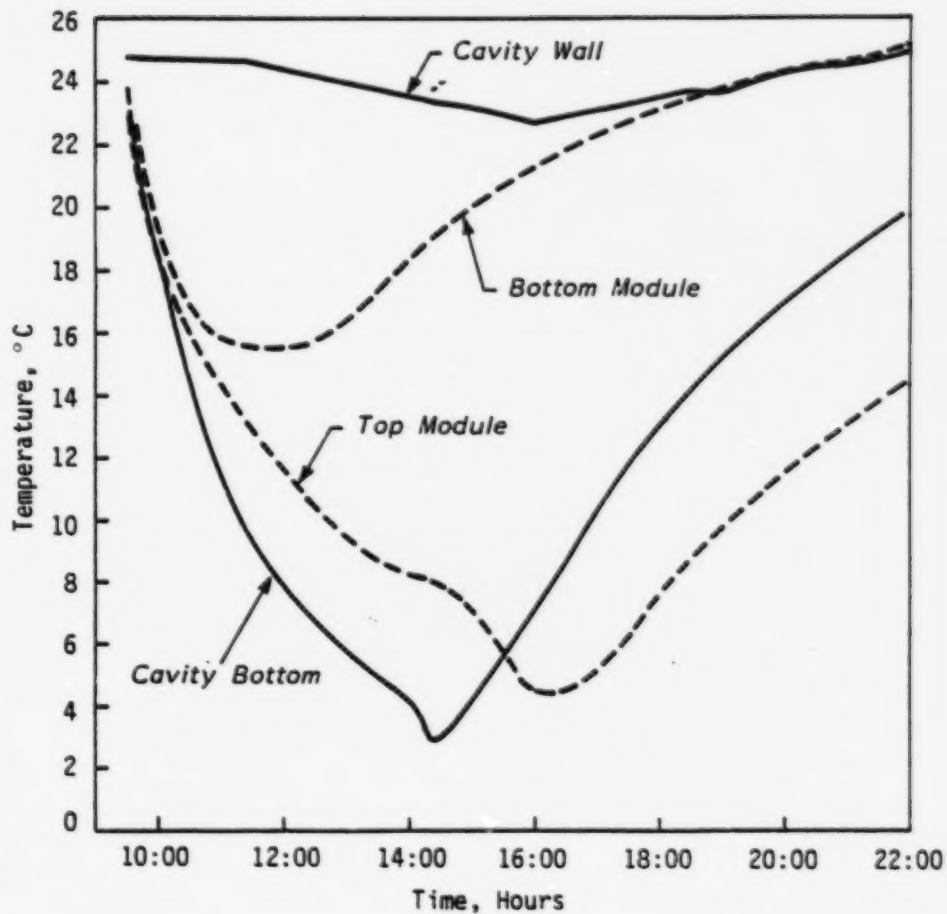


FIGURE 25
CAVITY WALL AND BOTTOM TEMPERATURES
AND FUEL MODULE TEMPERATURES
FOR A WATER FILLED AND DRAINED CAVITY

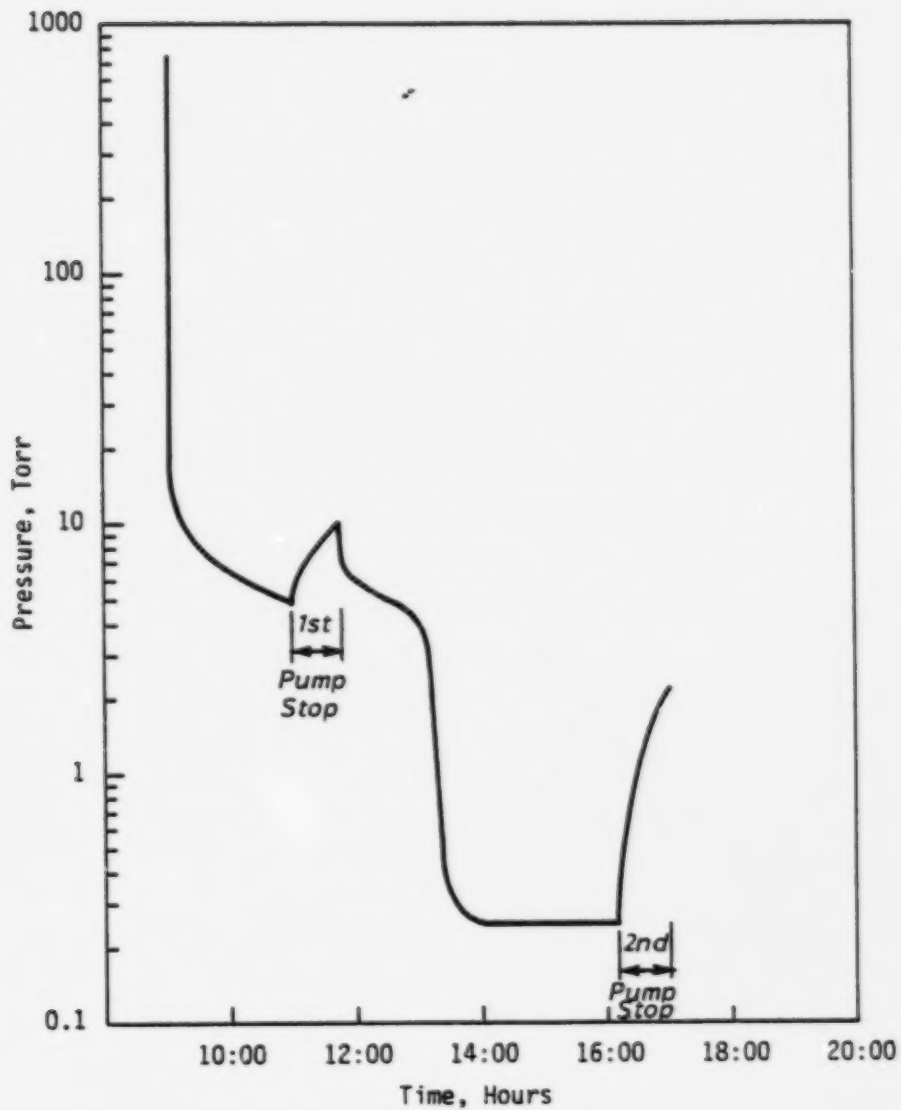


FIGURE 26
CAVITY PRESSURE WITH TWO PUMP-STOPPS
FOR 5 LITRES OF WATER

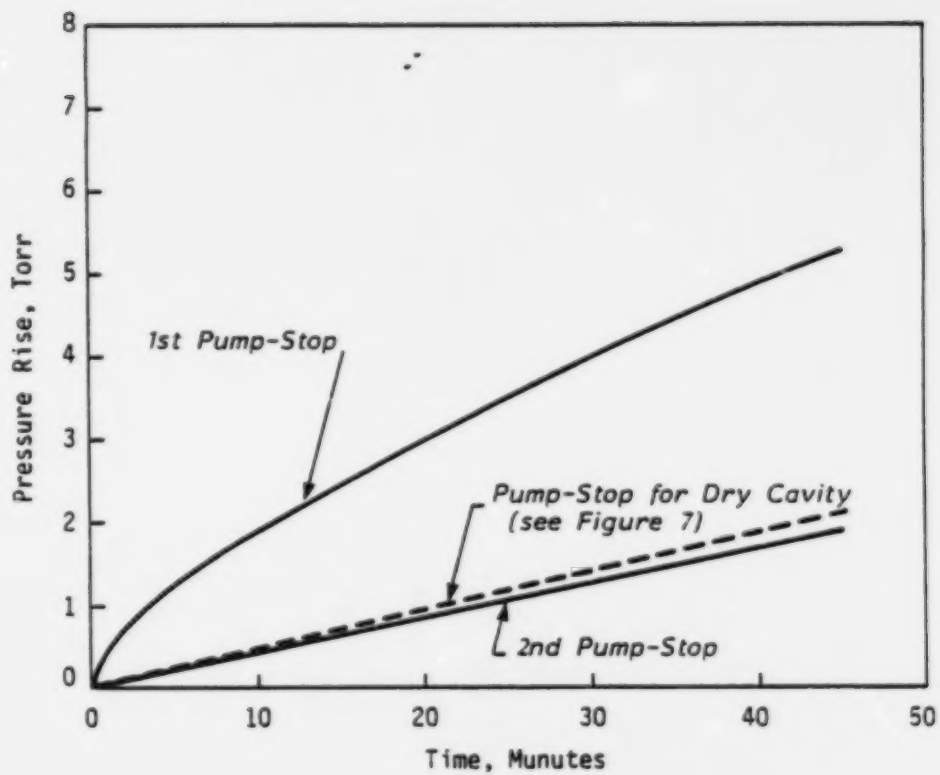


FIGURE 27
CAVITY PRESSURE RISE WITH
TWO PUMP-STOPPS FOR 5 LITRES OF WATER

TABLE 1
LIST OF VACUUM TEST CONDUCTED

Case No.	No. of Modules in Cavity	Volume of Water in Cavity (litres)	Measurements						
			$\dot{Q}$ (kW)	T_W (°C)	T_B (°C)	T_{TM} (°C)	T_{BM} (°C)	P_C (Torr)	L_W (mm)
1	0	0	0	Yes	Yes	-	-	Yes	-
2	0	Water Depth =100mm	0	Yes	Yes	-	-	Yes	Yes
3	0	Water Depth =100mm	1	Yes	Yes	-	-	-	Yes
4	0	5	0	Yes	Yes	-	-	Yes	-
5	0	10	0	Yes	Yes	-	-	Yes	-
6	0	15	0	Yes	Yes	-	-	Yes	-
7	0	20	0	Yes	Yes	-	-	Yes	-
8	2	Unknown	0	Yes	Yes	Yes	Yes	Yes	-

$\dot{Q}$ = Heat input to water

T_W = Temperature of cavity wall

T_B = Temperature of cavity bottom

T_{TM} = Temperature of top module

T_{BM} = Temperature of bottom module

P_C = Cavity pressure

L_W = Water level drop